A SEQUENTIAL DECISION-MAKING APPROACH TO POPULACE SCREENING IN COUNTERINSURGENCY OPERATIONS

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UNITED STATES
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THESIS

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SCREENING IN COUNTERINSURGENCY OPERATIONS

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ABSTRACT

An important problem in counterinsurgency is the screening of the populace through search and interrogation, so as to apprehend insurgents and their supporters. The problem is one of sequential decision making. Decisions must be made as to the frequency of operations and the duration of each and the size of the force to be used. Recursive relationships are developed describing the change in the insurgent population contingent upon whether screening operations occur. The cost criteria includes setup costs, unit screening costs, costs for insurgents presence in the area, and the cost of insurgents remaining at the end of the planning period. A numerical example is solved using a shortest-path algorithm from graph theory.

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CHAPTER I

INTRODUCTION

A recent article in a military magazine tells of an operation conducted by Vietnamese popular forces and district police with their American advisors and supporting elements.[6] The objective of this operation was to identify and neutralize the communist underground in a village. During the two weeks the forces were in the area, they attempted to identify and apprehend the members of the communist underground and their supporters. The government forces reorganized and retrained the village defense force, civic action programs were undertaken, and assistance was given in the fields of health, education, and agriculture. At the end of the two week operation the government forces had captured seventy-six communists. Two months after the forces left, the communists were able to again raid the village council office. Three months after the initial operation, a similar operation was conducted in the same village. During this operation, thirty communists were found. Some were agents that had escaped detection during the first operation, others were supporters recruited since that operation.

This narrative illustrates a question that faces many of the commanders of military units involved in counterinsurgency operations. That question is, given that insurgents are in an area, how often should forces enter the area to apprehend insurgents and neutralize the affects of their

organization. Another question is how long should the government forces stay in the area. In the narrative above, the forces stayed for two weeks the first time, and came back to the area after a period of two months. If the government operation had been of a longer duration the first time, it is possible that the interval between operations could be increased. It is the problem of controlling the number of insurgents in an area through the screening of the populace that we will discuss.

Definition and Phases of an Insurgency

Before discussing a particular problem area within the insurgent movement, it is appropriate to define an insurgency and discuss the characteristic phases of an insurgency. An insurgency may be defined as

> ... a subversive, illegal attempt to weaken, modify or replace an existing governing authority through the protracted use or threatened use of force by an organized group of indigenous people outside the established government structure.[5]

An insurgency is generally classified as having four phases.[1] In Phase I the social, economic, or political conditions may be such as to cause the population to be discontented with the present government. Also, the government may not be responsive to the people. If such issues are absent other factors may be exploited by groups which are attempting to gain control. Phase II starts with the forming of the insurgent organization for an armed insurrection. Underground cells are established as are communication and supply lines. Control by the insurgents

in the rural areas is a major objective. Phase III commences when insurgent control is established in the villages. With small units of squad and platoon size formed in Phase II, the larger insurgent units are formed. These units train in the rural areas which are under the insurgent's control, and they become more active as the phase progresses. By the end of Phase III the majority of the country's land mass is under the control of the insurgents. In Phase IV, the insurgent forces are strong enough to revert to conventional warfare. They have complete control except for government strongholds which may be under seige. Within one country it is possible to have various areas experiencing different phases of the insurgency at the same time. The model that is presented here is directed towards countering Phase II insurgency operations in which the insurgents are still attempting to gain control of an area, with most of their activities of a covert nature.

Neutralization of Insurgent Movement

In an insurgency, one of the tasks of the government's military forces is to eliminate or neutralize the insurgents with what is normally a constrained amount of resources. The number of men available for the military forces and for government civic programs is limited, as are funds to operate these forces and to maintain counterinsurgent programs. In underdeveloped countries, the cost constraint is probably more binding than the constraint on

available manpower. It is desirable that the government accomplish the needed results in the most cost-effective manner.

One method of neutralizing the insurgent movement is to separate the insurgents from the rest of the populace. The insurgents receive much of their supplies and intelligence from the population in which they move. By separating the two, the flow may be reduced or stopped completely. One method of separating the insurgents from the rest of the populace is by controls imposed on the population by the government, such as, controls on travel, controls on food, registration of individuals, and issuance of identification cards. Once these controls have been imposed, the government must see that the controls are being enforced and are effective. By establishing checkpoints where identification papers and travel permits may be inspected, and by conducting periodic searches of villages and interrogation of the residents, the government may be able to improve the effectiveness of the controls.

The forces available to carry out these missions may be military or paramilitary units, police units, or a combined force of both. The forces used for these operations are to be referred to as screening forces regardless of their composition. It is assumed that at any given time the maximum force available for screening operations is constrained by the size of the total forces and by other missions that may be permanently assigned to some of the units.

This paper is confined to one problem area in the neutralization of the insurgent force by searching and screening of the population. With a force of a given size available, it must be determined when the force should be employed and how long the operation should last. In the remainder of this paper, one approach is developed for solving this problem.

In the following chapters a decision model is developed for determining the minimum-cost plan for screening the populace of an area to find and apprehend those who are pro-insurgent. In Chapter II, a recursive function describing the dynamics of insurgent growth is developed together with a criterion function based on the costs of the screening program. In Chapter III, a procedure is given for finding the minimum-cost screening plan, and a numerical example is presented. In Chapter IV, possible extensions to the model are discussed.

CHAPTER II

DEVELOPMENT OF THE TOTAL-COST FUNCTION

In this chapter the total-cost function for the screening plan for an area in which insurgents exist is developed. A recursive function is developed relating the fraction of the population which is pro-insurgent at the start of one time period to the fraction pro-insurgent at the start of the next time period. This relationship and certain costs incurred by the government, are combined to form a cost function.

The model that is developed in this chapter is similar to a model that has been developed by Lindsay and Bishop.[3] They considered a multistage manufacturing process in which prior to each manufacturing operation an opportunity exists to inspect items for defects. The decision problem is, where in the process to inspect, and what level of inspection should take place. The objective is to find a minimum-cost plan for allocating inspection effort. The model developed in this chapter is for consecutive time periods. The defects are insurgents which exist in the populace of an area. The costs considered are the costs incurred by the government.

Classification of Individuals in the Populace

The population in an area in which an insurgent movement exists may be divided into seven groups according to the individual's sympathies and activities. These seven groups are,[4]

1. Guerrilla forces,
2. Underground members,
3. Insurgent sympathizers,
4. Uncommitted citizens,
5. Government sympathizers,
6. Government members, (civilians)
7. Security forces.

It should be noted that it is difficult to classify an individual as being a member of a particular group. The possible exceptions are persons who are classified as being guerrillas or underground members, and those who are classified as government members or members of the security forces. The individuals in Groups 3, 4, and 5 comprise the largest section of the populace. It is for the sympathies of this group that extreme groups are competing. For the development of the model, the population is divided into two groups, which are mutually exclusive and collectively exhaustive. One groups is referred to as the pro-insurgents, and includes those people in groups 1, 2, and 3 above. The remainder of the populace, groups 4, 5, 6, and 7, are referred to as non-insurgents.

<u>The Length of Time for Conducting one Screening Operation</u>

A time period is considered to be of length d weeks, where d is the shortest time that the screening force would be sent into an area to inspect. The length of the time period is determined by such factors as the time required to move into the area, the time required to establish

search or screening procedures and how long a time is required to inspect or search each individual or house. For example, if an inspection consists of only checking the identification card of an individual as he passes a village check point, this would require less time than an inspection which involved the investigating of an individual's background, occupation and political affiliation, and the issuing of an identification card. If the length of time under consideration for inspecting the area is assumed to be T weeks, the number of time periods is n, where n is the greatest integer in T/d. The time interval of T weeks under consideration will be referred to as the planning period. The length of the planning period may be determined by military or political requirements.

Screening Level and Screening Efficiency

If the screening force is sent for one time period into an area with a population N, then the expected total number of individuals inspected will be M. The size of the screening force, the density of the population in the area, and how the population is distributed throughout the area are factors on which M depends. The geographic distribution of the population affects the number of individuals screened in one time period by the force. For example, if the majority of the population is located in one village then the number screened would be greater than if the population is evenly distributed throughout the area.

The population N of an area is assumed to be constant throughout the development of this model. Even though, insurgents are removed from the populace when they are detected, it is felt that during the phase of the insurgency under consideration, the per cent of the population that is pro-insurgent may be small, and therefore the number of insurgents detected and removed from the area will not greatly effect the overall population.

The screening level, Q_k, is defined to be the fraction of the population inspected during time period k, and is the number of individuals screened, M, divided by the population N of the area. We assume that if screening is undertaken in time period k, the level will be Q. Therefore, $Q_k = (0,Q)$.

In conducting the screening operation, it is not likely that the screening force will correctly classify all pro-insurgent individuals inspected. The screening efficiency, η, is defined to be the probability that a person is classified as pro-insurgent when the person actually is pro-insurgent. The probability of classifying an individual as pro-insurgent when the person is actually a non-insurgent is assumed to be zero throughout the development of this model.

<u>Probability of Changing Allegiance</u>

During each time period in which screening is not undertaken, it is assumed that there is a probability that a person who is non-insurgent at the start of a time period will switch his allegiance during the period, and thus be

pro-insurgent at the end of the period. The person may switch due to dissatisfaction with the government, he may switch due to coercion by insurgents, or he may switch when it appears that the insurgents are gaining control, and seem to be winning. The probability that a person who is non-insurgent becoming pro-insurgent during a time period k of length d, is denoted by q_k. It is assumed that the probability of a pro-insurgent becoming non-insurgent during a time period is zero.

<u>Recursive Relationships for p_k</u>

As stated earlier, the population of the area is divided into two sets which are mutually exclusive and collectively exhaustive. The first set consists of those individuals who are pro-insurgents. The second set consists of all other individuals or non-insurgents. The fraction of the population which is pro-insurgent at the start of time period k is denoted by p_k. If there is no screening during time period k, then the fraction of the population which is pro-insurgent at the start of time period k+1, (the end of time period k) is equal to the fraction of the population which is pro-insurgent at the start of time period k plus the fraction of the population which changes allegiance from non-insurgent to that of pro-insurgent, or

$$p_{k+1} = p_k + q_k(1 - p_k). \qquad (1)$$

When an insurgent movement is just starting in an area and p_k is small, q_k, the probability of a non-insurgent

becoming a pro-insurgent is small. As the insurgency increases and the insurgent force becomes larger and more active, the probability of a non-insurgent becoming pro-insurgent is larger. The larger the insurgent movement becomes the more likely it will be that people will want to join it. It is assumed in the development of this model that the probability of an individual who is non-insurgent switching to a position of pro-insurgent during a time period when there is no screening is equal to the fraction of the population which is pro-insurgent at the start of that time period, i.e., $q_k = p_k$. Then (1) may be written as

$$p_{k+1} = p_k + p_k(1 - p_k),$$

or

$$p_{k+1} = 2p_k - p_k^2 . \tag{2}$$

Subtracting both sides of (2) from unity results in

$$1 - p_{k+1} = 1 - 2p_k + p_k^2 ,$$

or

$$1 - p_{k+1} = (1 - p_k)^2 ,$$

when the screening level is zero. If there is no inspection during time period k, the fraction of the population which is pro-insurgent at the start of time period k+1 is

$$p_{k+1} = 1 - (1 - p_k)^2 . \tag{3}$$

The pro-insurgent fraction of the population at the beginning of time period k+2 given no screening during the time period k and k+1 is

$$p_{k+2} = 1 - (1 - p_{k+1})^2 .$$

When (3) is substituted in the equation above, we have

$$p_{k+2} = 1 - \left[(1 - p_k)^2\right]^2$$

or

$$1 - p_{k+2} = (1 - p_k)^{2^2} .$$

Proceeding in a similar manner, the fraction of the population which is pro-insurgent at the start of time period k+3 given no screening in time period k, k+1 and k+2 is

$$p_{k+3} = 1 - (1 - p_{k+2})^2 ,$$

and replacing $1 - p_{k+2}$ with $(1 - p_k)^{2^2}$ results in

$$p_{k+3} = 1 - \left[(1 - p_k)^4\right]^2 .$$

or

$$1 - p_{k+3} = (1 - p_k)^{2^3} .$$

Continuing in a similar manner, we find that P_{k+r} given that $Q_j = 0$, for $j = k, k+1, \ldots, k+r-1$, is

$$p_{k+r} = 1 - (1 - p_k)^{2^r} . \qquad (4)$$

We assume that the probability of an individual changing his allegiance from non-insurgent to pro-insurgent is zero during those time periods that the screening force is in the area. Then the fraction of the population which is pro-insurgent at the start of time period k+1 equals the fraction P_k of the population which is pro-insurgent at the start of time period k, minus the fraction of the insurgent population that is detected during time period k, $p_k \eta Q$. The recursive equation for the fraction of the populace which is pro-insurgent at the start of time period k+1, when the screening level Q_k is greater than zero, is

$$p_{k+1} = p_k - \eta Q p_k ,$$

or

$$p_{k+1} = p_k (1 - \eta Q). \qquad (5)$$

If the screening level is greater than zero for time period k and k+1, then

$$p_{k+2} = p_{k+1} (1 - \eta Q).$$

If (5) is substituted into the above equation then

$$p_{k+2} = p_k (1 - \eta Q)(1 - \eta Q).$$

Following the same procedure for p_{k+3}, given screening takes place during time period k, k+1, and k+2,

$$p_{k+3} = p_{k+2} (1 - \eta Q)$$

and

$$p_{k+3} = p_k(1 - \eta Q)(1 - \eta Q)(1 - \eta Q).$$

In general, the fraction of the populace which is pro-insurgent at the start of time period k+r, given the screening force is in the area from time period k to k+r-1 is

$$p_{k+r} = p_k(1 - \eta Q)^r \tag{6}$$

if $Q_j > 0$, j=k, k+1, ..., k+r-1.

<u>Costs to the Government</u>

In establishing the screening program, both the cost to the government of the screening operations and the costs to the government of having insurgents in the area must be considered. The screening cost, I_k, for time period k is defined as the cost to the government of screening one individual during time period k. The cost to the government, D_k, of having insurgents in an area during time period k, is defined to be the cost to the government of having an insurgent in the area during time period k.

The screening cost includes costs associated with the searching and screening of the area during a time period. It may include but is not limited to such costs as the pay of the force personnel and the cost of maintaining the force during the period. The screening cost may include an item such as the loss in taxes due to the screening operations curtailing commerce and business in the area. An opportunity cost, which is a cost incurred by the government for not having the screening forces available to be employed elsewhere may also be included.

The cost of having insurgents in the area includes the amount of damage an insurgent can do. For example, the amount of 'taxes' an insurgent collects from the non-insurgents populace, the cost of the food, arms or other provisions he can provide the insurgency, may all be included in the cost of the insurgents. Other items that may also be included are the cost to rebuild or repair facilities the insurgent can destroy or damage, and the cost of providing security in the area due to the insurgent's presence.

This short discussion of each of the costs is not meant to imply that determining these costs is easy, nor is it to imply that the exact cost may be determined. It may be possible to determine the costs to within only a reasonable range of values. Sensitivity analysis may be used to see how varying the cost affects the solution to the problem.

The cost to the government during time period k is then the cost of inspecting NQ individuals, plus the cost of having the insurgents in the area. The average number of insurgents in the area during the time period is used in determining the insurgent cost to the government. The average number of insurgents in time period k is determined by averaging the number of insurgents at the start of time period k and k+1. The cost to the government for time period k is denoted by $C_k(Q_k)$, and is

$$C_k(Q_k) = I_k N Q_k + D_k N \left[\frac{p_k + p_{k+1}}{2}\right] . \qquad (7)$$

If Q_k, the screening level, is zero, then from (7),

$$C_k(0) = D_k N \left[\frac{p_k + p_{k+1}}{2}\right]$$

where

$$p_k + p_{k+1} = p_k + 1 - (1 - p_k)^2$$

$$= p_k + 1 - 1 + 2p_k - p^2_k$$

$$= 3p_k - p^2_k \; .$$

Then the cost to the government for time period k from (7) is

$$C_k(0) = D_k N \left[\frac{3p_k - p^2_k}{2}\right] \qquad \text{when } Q_k = 0.$$

If Q_k is greater than zero, i.e., $Q_k = Q$, then

$$p_k + p_{k+1} = p_k + p_k(1 - \eta Q)$$

$$= p_k(2 - \eta Q)$$

and

$$C_k(Q) = I_k NQ + D_k N \left[\frac{p_k(2 - \eta Q)}{2}\right].$$

The total-cost, TC, to the government for a planning period is the sum of the costs for each of the n time periods, or

$$TC = \sum_{k=1}^{n} C_k(Q_k) = \sum_{k=1}^{n} I_k N Q_k + D_k N \left[\frac{p_k + p_{k+1}}{2}\right] . \qquad (8)$$

Assuming that the screening costs, I_k, and the insurgent costs, D_k, do not vary between time periods, then (8) may be written as

$$TC = \sum_{k=1}^{n} C_k(Q_k) = \sum_{k=1}^{n} INQ_k + DN\left[\frac{p_k + p_{k+1}}{2}\right] . \qquad (9)$$

Setup Costs

In the development of the total-cost function, (9), the only costs considered are the unit screening costs, I, and the costs to the government of having each insurgent in the area, D. An additional cost that must be considered is a setup cost. The setup cost is the cost incurred to go into an area, establish and setup a force to screen, it may also include the cost of training the screening force. The setup cost incurred during time period k is denoted by S_k. A force which is in an area screening for one of more consecutive time periods incurs the setup cost only when it first enters the area. The setup cost is assumed to be a constant cost that the force incurs when it re-enters an area after not screening for one or more time periods. We may now write the total-cost function as,

$$TC = \sum_{k=1}^{n} C_k(Q_k) = \sum_{k=1}^{n} INQ_k + DN\left[\frac{p_k + p_{k+1}}{2}\right] + S_k\varepsilon \qquad (10)$$

where ε is zero if Q_{k-1} is Q and is one if Q_{k-1} is zero.

Protection Cost

At the end of the planning period, the screening force may be withdrawn from the area. With its departure, local forces in the area would assume the missions of protecting the people and the government facilities. An example of this is in the article referred to in Chapter I, where the

mere presence of the popular forces helped protect the village, even though this was not the primary mission of the force. When the popular forces left the village, the defense or the security of the village was the responsibility of the village defense force. It is reasonable to assume that the size of the defense force would depend on the seriousness of the threat to the village. The greater the pro-insurgent fraction of the populace, the greater is the threat to the villagers. As the size of the defense force increases so does the cost of maintaining it.

The cost of providing this security or protection to the non-insurgent populace will be termed the protection cost. This cost is assumed to be proportional to the fraction of the population which is pro-insurgent at the end of the planning period. The protection cost is defined to be the product of the cost L to the government of providing security forces in an area in which screening of the populace has terminated, per insurgent in the area at that time, and the number of insurgents, i.e., LNP_{n+1}. Adding the protection cost to (10) we find that

$$TC = \sum_{k=1}^{n} C_k(Q_k) + LN\, p_{n+1} \tag{11}$$

$$= \sum_{k=1}^{n} INQ_k + DN\left[\frac{p_k + p_{k+1}}{2}\right] + S_k\varepsilon + LN\, p_{n+1} \text{ ,}$$

where ε is zero if Q_{k-1} is Q and is one if Q_{k-1} is zero.

With the total-cost function developed, the next problem is to find a sequence of screening decisions, Q_1, Q_2,

..., Q_n, such that the total-cost function, (11) is a minimum. In the next chapter, a procedure for determining the sequence of screening levels that minimizes the total-cost function will be developed.

CHAPTER III

DETERMINING THE MINIMUM TOTAL-COST SCREENING PLAN

In this chapter a procedure is presented to identify those time periods during which screening operations should be scheduled. The procedure is illustrated with a numerical example. Two possible heuristics which could reduce the amount of calculations necessary to determine the proper sequency of screening operations are discussed in the last section.

Procedure to Determine Minimum-Cost Screening Plan

Before showing the procedure for determining the minimum-cost screening plan, we shall simplify the equations for the cost function $C_k(Q_k)$ by introducing three new variables, B, W and Z. The total cost to the government for a screening plan is the sum of the costs for each of the n time periods. The cost for each time period, $C_k(Q_k)$, depends on the screening level for that period. Setting Q_k equal to zero, we have

$$C_k(0) = \frac{DN}{2}\left[p_k + 1 - (1 - p_k)^2\right] . \qquad (12)$$

Let B be defined as ηQ and Z is defined to be equal to DN/2B, substituting Z into (12) and simplifying, we have

$$C_k(0) = ZB(3p_k - p_k^2) . \qquad (13)$$

Setting Q_k equal to Q, the cost function for time period k is

$$C_k(Q) = INQ + \frac{DN}{2}\left[p_k + p_k(1 - \eta Q)\right] + S_k\varepsilon ,$$

where ε is zero when Q_{k-1} is Q and is one when Q_{k-1} is zero. Substituting Z, B, and W, where W is defined to be equal to IN/η, in the above equation, results in

$$C_k(B) = WB + BZ(2p_k - p_kB) + S_k\varepsilon, \tag{14}$$

where ε is zero when Q_{k-1} is Q and is one when Q_{k-1} is zero.

The procedure used to find the minimum total-cost screening plan is from the theory of graphs, and is used to find the shortest path between two points in a graph. Before explaining the procedure, some definitions from the theory of graphs must be presented. A graph is a set of points connected to one another by lines. The points are called nodes and are juncture points for the lines connecting them. The lines joining the modes are referred to as arcs. The length of an arc connecting node a and node b may be the distance between the two nodes.[2] For the minimum total-cost screening plan, the length of the arcs is the cost of going from node a to node b. The nodes of the graph in our problem are points in time, i.e., the beginning of each time period k. The origin node of the graph is the point from which the path begins and the terminal node is the destination of the path.

To solve the minimum total-cost problem by use of the theory of graphs, the nodes are considered to be the fraction of the population which is pro-insurgent at the start of each time period. Time period k will have 2^{k-1} nodes.

The node $p_{k,j}$ is the j^{th} node in time period k. The length of an arc connecting two nodes is the cost to the government, $C_k(Q_k)$, to go from one node to another. Since the screening for each time period is either at a zero level or at Q, there are two arcs incident from each node, for time periods 1 through n. There is one arc incident from each node in time period n+1, that represents the protection cost to the government at the end of time T. For nodes in time period 1 to n, one arc incident from a node k,j is the cost to the government when a screening operation is conducted, including setup costs, if applicable. The setup cost is applicable if, the arc incident to node k,j is the cost when no screening occurs in time period k-1. The second arc is the cost to the government for not screening. In Figure 1 is an example of a graph for determining the minimum total-cost screening plan with n equal to four, i.e., four time periods. Only one arc is incident from each of the 2^n nodes in time period n+1 and is incident to the terminal node. The length of each of these arcs represent the protection cost, which depends on $P_{n+1,j}$. The minimum total-cost screening plan is represented in the graph by the shortest path from node $p_{1,1}$ to the terminal node.

Solving the Shortest-Path Problem

What is presented below is just one method of solving the shortest-path problem. The algorithm is presented first in general terms and is then followed by a numerical

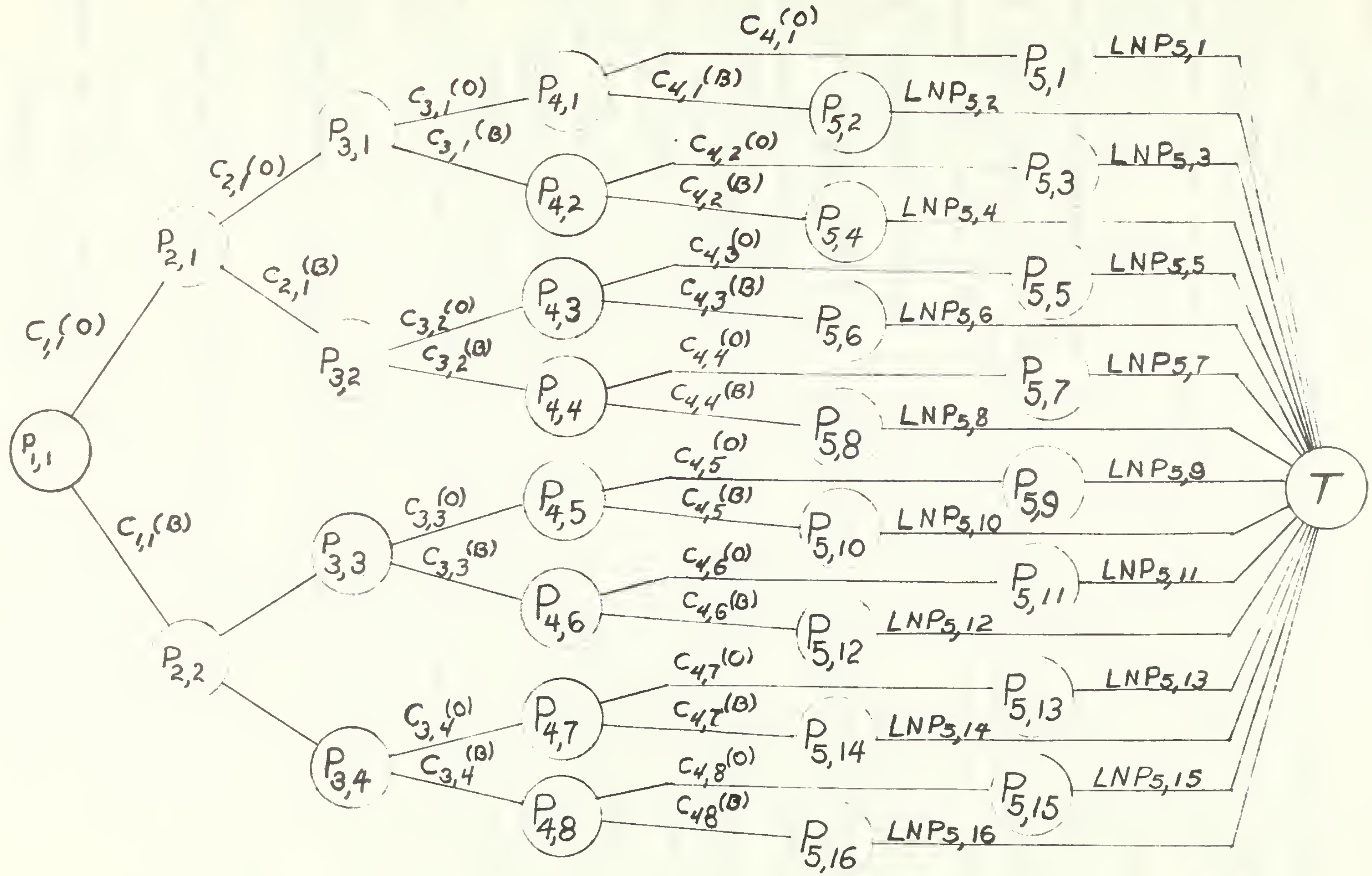

FIGURE 1

SCREENING PLAN GRAPH WITH FOUR TIME PERIODS.

example, which is shown in Figure 1 in graph form. First the origin node is marked with a zero. We next determine nodes having an arc incident to them which is incident from the origin node. For each such node, we will determine its distance from the origin node. Having determined the distance for each node, we will determine the node with the minimum distance and mark it with this distance. At this point there are two marked nodes. Again we will determine the nodes each having an arc incident to it which is incident from a marked node. For each node we found, its distance from the origin is determined. The node with the minimum distance is marked with this distance. We continue this procedure until the terminal node is marked. The path of marked nodes from the origin to the terminal node is the shortest path and the distance that marks the terminal node is the length of the path. If when determining which node is the next to be marked there are two or more nodes with the same minimum distance from the origin, mark all such nodes and continue as before.

We may summarize the procedure presented above as follows:

1. Mark the initial node.
2. Find the unmarked nodes that are connected to marked nodes.
3. For each such node calculate its distance from the origin.
4. Determine which of the unmarked nodes is nearest the origin and mark it with the distance.

5. If the node marked in step 4 is the terminal node, the shortest path has been marked, if it is not, return to step 2.

In the cost problem we are addressing, the arcs are labeled with the costs incurred by the government during a time period k. An arc labeled with $C_{k,j}(0)$, where $C_{k,j}(0)$ is equal to 4.2, indicates it costs the government 4.2 units if it does not screen during time period k, given the fraction of insurgents is that indicated at the node $p_{k,j}$, from which the arc originates.

In Table I, $C_{2,1}(0)$ is the cost to the government if there is no screening in time period 2, given the fraction of insurgents at the start of time period 2 is $p_{2,1}$, $C_{2,1}(0)$ equals \$296,520. The cost to inspect in time period 2, given $p_{2,1}$ is $C_{2,1}(B)$ and is equal to \$215,375.

The nodes are labeled with the fraction of the population which is pro-insurgent at the start of the time period, given the screening plan indicated by the arcs from the origin to the node is followed. The fraction of insurgents at the start of time period 3, given no screening during time period 1 and 2, is $p_{3,1}$ and is equal to 0.0394. Following a path from the origin to node $p_{4,3}$, in Figure 1, it is found that $p_{4,3}$ is the result of not screening during periods 1 and 3 and screening during period 2. This results in $p_{4,3}$ having a value of 0.02963.

TABLE I

CALCULATED VALUES FOR NODES AND

ARCS FOR THE NUMERICAL EXAMPLE

k	j	P_{kj}	$C_{kj}(0)$	$C_{kj}(B)$
1	1	0.01000	$149,500.	$128,750.
2	1	.01990	296,520.	215,375.
2	2	.00750	112,219.	96,875.
3	1	.03940	583,296.	386,035.
3	2	.01492	222,761.	161,844.
3	3	.01494	223,039.	172,008.
3	4	.00562	84,217.	80,469.
4	1	.07726	1,128,986.	717,233.
4	2	.02996	438,927.	289,838.
4	3	.02963	440,019.	300,488.
4	4	.01119	167,280.	129,195.
4	5	.02966	440,562.	300,811.
4	6	.01121	167,489.	129,318.
4	7	.01122	167,646.	139,410.
4	8	.00422	63,192.	68,164.

k	j	P_{kj}	Protection Cost for Node k,j
5	1	0.14854	$1,485,421.
5	2	.05794	579,414.
5	3	.05823	582,326.
5	4	.02216	221,647.
5	5	.05838	583,767.

TABLE I (continued)

k	j	P_{kj}	Protection Cost for Node k,j
5	6	0.02222	$222,204.
5	7	.02226	222,622.
5	8	.00840	83,953.
5	9	.05845	584,483.
5	10	.02225	222,481.
5	11	.02229	222,900.
5	12	.00841	84,059.
5	13	.02231	223,108.
5	14	.00841	84,138.
5	15	.00842	84,197.
5	16	.00316	31,641.

Note: The protection cost for node k,j is calculated prior to rounding off of p_{jk}. All costs are rounded off to the nearest dollar.

A Numerical Example

In the example in Figure 1, the assumed data is;

Screening level, Q	= 0.3125
Screening efficiency, η	= 0.80
Fraction of populace pro-insurgent at start of time period one, $p_{1,1}$	= 0.10
Cost to government to screen one individual, I	= \$10.00
Cost to government per insurgent in the area, D	= \$1000.00
Setup cost to the Government, S	= \$10,000.00
Protection cost to the Government, LNp_{n+1}	= $\$(p_{n+1} \times N \times 10^3)$
Population of Area, N	= 10,000
Number of time periods, n	= 4

Using this data the following terms are determined;

$$B = \eta Q = (0.8)(0.3125) = 0.25$$

$$W = \frac{IN}{\eta} = \frac{(10)(10{,}000)}{0.8} = 1.25 \times 10^5$$

$$Z = \frac{DN}{2B} = \frac{(1000)(10{,}000)}{(2)(0.25)} = 2 \times 10^7$$

The cost for each arc and the fraction of the populations which is pro-insurgent for each node, Table I, is determined by using (13), (14), (3) and (5). It should be noted that it is not necessary to calculate all the values that are in Table I as has been done. In solving the minimum-cost problem, only the fraction pro-insurgent

and the costs related to the nodes under consideration to be marked need be calculated. Using the values from Table I, an example is given below illustrating the procedure described in the previous section. The node representing the initial insurgent fraction of the population, $p_{1,1}$, is the first node marked and is the origin. The next node to be marked is the node that is nearest the origin. To find which node it is, the cost to go from the origin to each of the nodes, $p_{2,1}$ and $p_{2,2}$ is calculated. The minimum cost is found to be to node $p_{2,2}$ with a cost of \$128,750. Therefore node $p_{2,2}$ is marked with its total-cost. The total-cost to the government, $TC_{k,j}$, for screening operations and insurgents' presence in the area for the first k-1 time periods, is the sum of the cost arcs from the origin to the node $p_{k,j}$. The next step is to determine which nodes are connected to the marked nodes. The nodes $p_{3,3}$ and $p_{3,4}$ are connected to marked mode $p_{2,2}$ and node $p_{2,1}$ is connected to the origin. To determine which node is to be marked next, $TC_{3,3}$, $TC_{3,4}$, and $TC_{2,1}$ are evaluated and compared. The total costs are found to be \$240,969, \$225,625 and \$149,500 respectively. Since $TC_{2,1}$ is the minimum, node $p_{2,1}$ is marked with its total-cost. At this point, nodes $p_{1,1}$, $p_{2,1}$ and $p_{2,2}$ are marked and the total-costs for nodes $p_{3,1}$ and $p_{3,2}$ have to be determined so that they may be compared to $TC_{3,3}$ and $TC_{3,4}$. The four nodes in time period 3 are unmarked nodes connected to marked nodes.

TABLE II

TOTAL COST FOR NODES IN TIME PERIOD 3

k	j	TC_{kj}
3	1	$446,020
3	2	364,875
3	3	240,969
3	4	225,625

From Table II it may be seen that node $p_{3,4}$ has the minimum total-cost and is to be marked.

Repeating the steps given in the previous section, the next node marked is $p_{3,3}$, followed by node $p_{4,8}$. At this stage the marked nodes are $p_{1,1}$, $p_{2,1}$, $p_{2,2}$, $p_{3,3}$, $p_{3,4}$, and $p_{4,8}$. Table III lists the unmarked nodes which are connected to the marked nodes.

TABLE III

TOTAL COST FOR UNMARKED NODES

CONNECTED TO MARKED NODES

k	j	TC_{kj}
3	1	$446,020
3	2	364,875
4	5	464,006
4	6	412,977
4	7	309,842
5	15	369,286
5	16	374,258

From the table, it may be seen that node $p_{4,7}$ has the minimum total-cost and is marked. Repeating the procedure of finding new unmarked nodes and calcualting their total-cost, the next node to be marked is $p_{3,2}$ followed by $p_{5,15}$.

At this point it is necessary to calculate the protection cost for node $p_{5,15}$. The protection cost equals the product of the number of pro-insurgents in the population at the start of time point n+1, and a constant. The constant is the cost of protecting the area per insurgent. In this example, the cost is assumed to be $1000. per insurgent. Using the protection cost from Table I for node $p_{5,15}$, the total-cost for the terminal node through this node is $453,483. Comparing this total-cost with the total-cost for other unmarked nodes, $p_{5,16}$ is marked.

The protection cost from Table I, plus the total-cost for node $p_{5,16}$ results in a total-cost for the terminal node for the path through $p_{5,16}$ of $405,899. This total-cost is compared to the total-cost for the other nodes which are unmarked and connected to marked nodes. The result of this comparison is that the total-cost for the terminal node with the path through $p_{5,16}$ is the minimum. Therefore the terminal node is marked.

With the terminal node marked, the minimum total-cost path has been determined. The path is from the origin through marked nodes p_{22}, p_{34}, p_{48}, and p_{516} to the terminal node. This path results in a total cost to the government of $405,899, and corresponds to screening during

each of the four time periods, with the given force.

This plan results in the fraction of the population which is pro-insurgent being reduced from an average of ten per thousand to an average of three per thousand.

Heuristics Solutions

The example in the previous section illustrates a drawback to the use of the shortest path algorithm to find the minimum-cost screening plan. This is the rate at which the number of possible paths increase with an increase in n, the number of time periods. In a problem where the number of time periods is ten, at the end of the tenth time period there are 2^{10}, or 1024 possible paths from the origin to the terminal node. For a problem with n time periods, the number of possible paths is 2^n. It may not be necessary to check all the paths to find the path corresponding to the minimum-cost plan but the amount of calculation still could be quite large. A computer program could be written that could do all the calculations required and determine the minimum-cost path, but for an individual attempting to solve the problem which has a large number of time periods, a heuristic he could follow may save him hours of work.

A basic concept underlies each of the two approaches used to derive a heuristic. The first concept is to consider only one time period at a time, and to take that action which costs the least in that period, i.e., screen the populace or not. For example in time period one, assume

that it is less costly to screen than not to screen. You would then decide to screen the populace. At the start of the second time period you will have reduced the pro-insurgent fraction of the populace. Using the resultant p_2, you would determine what would be the least costly action for the second time period, given you screened in the first period. Following the heuristic, you would continue to select the least costly action for each time period k, given p_k.

Using the values for the previous example in Table I, and our heuristic, we find that for the first time period we would screen the populace, since $C_{1,1}(B)$ is less than $C_{1,1}(0)$. With the pro-insurgent fraction of the populace now being equal to $p_{2,2}$, for the second time period again we would screen, since $C_{2,2}$ (B) is less than $C_{2,2}(0)$. Continuing in the same manner in the third time period we would screen, but in the fourth period we would not since $C_{4,8}(0)$ is less than $C_{4,8}(B)$. Adding the protection cost for node $p_{5,15}$ to the costs for the four time periods, we find a total-cost for this screening plan to be $453,483, which is not too great an increase over the optimal solution of $405,899. In other examples on which this heuristic has been used, the results have not been good, in that the solution which results is some times one of the most costly. This is a result of being off the path for the optimal solution in the early time periods. Once the path using the heuristic is off the optimal path, there is no way to return to it.

The concept underlying the second approach to a heuristic is that the screening plan is cyclic. There is a phase when screening operations are conducted for a number of consecutive time periods, followed by a phase when no screening is done for a number of time periods, followed again by a phase of screening. The second approach is to determine the length of a phase of screening or of no screening, given the pro-insurgent fraction of the population at the start of the phase. If a sequence of time periods during which screening occurs starts with time period k and ends with time period k+r, we want to determine what r is. The same is true of a sequence of time periods during which no screening is taking place. A sequence of time periods during which no screening occurs is assumed to terminate when it is less costly to screen than not,

$$C_{k+r}(B) < C_{k+r}(0) \tag{15}$$

where

$$C_{k+r}(0) = ZB(3p_{k+r} - p^2_{k+r}), \tag{16}$$

and

$$C_{k+r}(B) = WB + ZB(2p_{k+r} - p_{k+r}B) + S_{k+r} \tag{17}$$

Substituting in the two equations above for p_{k+r}

$$p_{k+r} = 1 - (1 - p_k)^{2^r}$$

and simplifying, (15) may be written

$$\frac{W}{Z} - B + \frac{S_{k+r}}{ZB} < (1 - B)(1 - p_k)^{2^r} - (1 - p_k)^{2^{r+1}} . \qquad (18)$$

Using this inequality, the largest integer value of r satisfying it is determined. Then the sequence of no screening operations ends with the termination of time period k+r-1.

The same method is used to determine when a sequence of consecutive time periods in which screening operations are conducted terminates. In this case,

$$C_{k+r}(B) > C_{k+r}(0) \qquad (19)$$

and screening has been conducted since time period k. The fraction in this insurgent p_{k+r} is

$$p_{k+r} = p_k(1 - B)^r \qquad (20)$$

Substituting (20) in for p_{k+r} in (19) and simplifying, we have

$$\frac{W}{Z} > p_k(1 - B)^r(1 + B - p_k(1 - B)^r). \qquad (21)$$

Again the largest integer value of r for which the inequality holds is determined. By using (18) and (21) and the recursive equations for p_k, it is possible to determine the length of the sequences of screening and no screening and to construct a screening plan. Employing this method on the example problem, results in a path of nodes $p_{1,1}$, $p_{2,2}$, $p_{3,4}$, $p_{4,8}$ and $p_{5,15}$. As before, the cost of this path is

somewhat greater than the optimal. In other examples, the difference between the optical solution and the solutions using this heuristic is extremely large. Again the problem is when the path using the heuristic becomes non-optimal and there is no way to get back to the optimal path.

CHAPTER IV

SUMMARY AND RECOMMENDATIONS

In Chapters II and III, one method of solving the problem of when to screen the populace of an area has been developed. The model developed is one of sequential decision making, where at specific points in time decisions are made whether to screen the populace or not.

In Chapter II, a recursive relationship has been developed which relates the pro-insurgent fraction of the population at the start of a time period with the fraction at the start of the previous time period. A cost function based upon cost of the screening operation, the cost of the insurgents being in the area, the cost of setting up or initiating a screening operation, and the cost of insurgents being in the area at the termination of all screening operations has also been developed. In Chapter III, a procedure has been developed for finding the minimum-cost screening plan using a shortest-path algorithm from the theory of graphs. Through this procedure it may be possible to find the minimum-cost solution without evaluating all possible screening plans.

Areas for Further Studies

In the development of the model, the only criterion used has been the cost to the government. No attempt has been made to integrate this model into the overall counter-insurgency strategy. It has been isolated from other

possible programs that the government may institute to compliment the screening operations, such as a pacification program, or large-scale military operations. If the insurgents are active militarily then operations which will reduce their military capabilities would probably be conducted. Pacification programs may be deemed necessary to increase the people's allegiance to the government.

A number of assumptions have been made during the development of the model, all of which are areas for further study and possible refinement. It has been assumed that the probability that a person who is non-insurgent becoming pro-insurgent during a time period being equal to the pro-insurgent fraction of the population at the start of the time period. This seems a reasonable approximation, but the impact of other relationships on the model could be investigated.

It has been assumed that the probability of a non-insurgent becoming pro-insurgent is zero when the government is in the area screening. If this assumption is dropped, the problem may have to be structured differently. The screening operations might be conducted in such a manner as to antagonize the populace, and thus increase the number of people who are pro-insurgent.

Another simplification has been the partitioning of the populace into two sets, pro-insurgents and non-insurgents. Each set has been treated as if it is homogeneous, all types of individuals being equally difficult to

detect if they are insurgents, or being equally difficult to convert if they are government supporters. It has also been assumed that the cost to the government is the same for each insurgent for the time they are allowed to be in an area. A further extension of this model would be to subdivide each of the two groups into a hierarchy of subgroups, along with related probabilities and costs.

The assigning of values to the parameters is an area which may be examined further. Methods should be studied so that the most accurate values for the screening level, the screening efficiency, and the initial pro-insurgent fraction of the population may be obtained for use in the model. The problem of estimating the cost involved in the cost function is extremely difficult. It may be necessary to do sensitivity analysis to determine how variations in the costs affect the results of the model for given values of the other parameters.

An extension of the problem of the minimum-cost screening plan is to consider what size screening force should be used, such that Q_k may vary between zero and some Q_{max}. The upper limit Q_{max} would be when all available screening forces were used in the area during a time period. Another extension is the problem of when to screen, given there is more than one area under consideration, but the forces are not adequate to screen all areas simultaneously. It may be found that the forces should be divided into a number of smaller forces and each assigned

a number of areas to screen. The entire force may be kept as one unit and rotated among the different areas. What exists is a queuing problem where the areas are waiting to be serviced.

There may exist military or political requirements that the pro-insurgent fraction of the populace is to be less than some given value q'_{n+1} at the end of the planning period. The problem of determining the minimum-cost screening plan where q_{n+1} must be less than q'_{n+1} is another possible extension.

As it may be seen, what has been done in this paper is just a beginning in the development of one approach to the problem of population screening and search. On this approach alone, much remains to be studied, along with investigating other possible methods of treating the problem.

BIBLIOGRAPHY

1. HAURON, M.D., J.A. Whittenburg, and A.T. Rambo. U.S. Army Handbook of Counterinsurgency Guidelines for Area Commanders, An Analysis of Criteria. Department of the Army pamphlet, no. 550-100, Prepared for the Department of the Army by Special Operations Research Office, The American University, Washington, D.C., 1966.

2. HILLIER, Frederick S., and Gerald J. Lieberman. Introduction to Operations Research. San Francisco: Holden-Day, Inc., 1967

3. LINDSAY, Glenn F., and Albert B. Bishop. "Allocation of Screening Inspection Effort - A Dynamic-Programming Approach," Management Science, 10:342-352, January, 1964.

4. LYBRAND, William A. "Support, People, Control, Influence," Proceedings 11th Military Operations Research Symposium, Limited War Research, pp. 54-59, sponsored by the Office of Naval Research, Spring 1963. (SECRET)

5. MOLNAR, Andrew R., Jerry M. Tinker and John D. LeNoir. Human Factors Considerations of Undergrounds in Insurgencies, Department of the Army pamphlet no. 550-104, prepared by Special Operations Research Office, The American University, Washington, D.C., 1966.

6. SWENSON, Louis S., Major, USA. "The Revolutionary Development Program," Infantry, 58:28-31, January-February, 1968.

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13. ABSTRACT

An important problem in counterinsurgency is the screening of the populace through search and interrogation, so as to apprehend insurgents and their supporters. The problem is one of sequential decision making. Decisions must be made as to the frequency of operations and the duration of each and the size of the force to be used. Recursive relationships are developed describing the change in the insurgent population contingent upon whether screening operations occur. The cost criteria includes setup costs, unit screening costs, costs for insurgents presence in the area, and the cost of insurgents remaining at the end of the planning period. A numerical example is solved using a shortest-path algorithm from graph theory.

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